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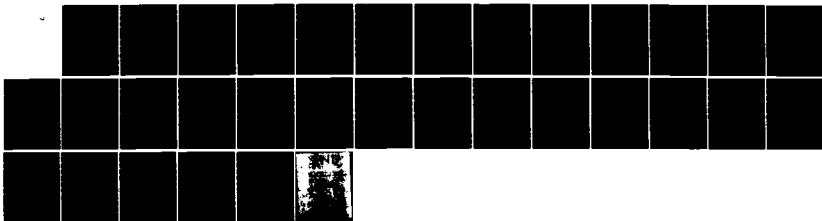
A SEABORNE NAVIGATION TRIAL UTILISING A DIFFERENTIAL  
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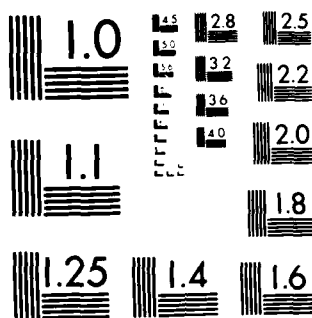
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ERL-0295-TM

A SEABORNE NAVIGATION TRIAL UTILISING A DIFFERENTIAL OMEGA SYSTEM

J.H. SILBY

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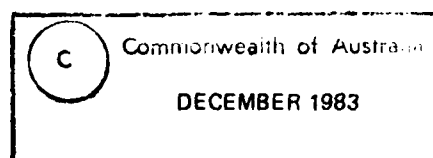
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TECHNICAL MEMORANDUM

ERL-0295-TM

A SEABORNE NAVIGATION TRIAL UTILISING A DIFFERENTIAL OMEGA SYSTEM

J.H. Silby

S U M M A R Y

A Sea trial was conducted in the first half of 1983 to test the accuracy of Differential Omega at sea and to compare the results with those obtained on land in the Pilbara region in 1980. Base stations were established at Albany and Esperance in Western Australia. Position measuring equipment utilising the Differential Omega system was set up on board HMAS Moresby and positions obtained by the Differential Omega system were compared with those obtained by the Argo system. This report describes the exercise and discusses the results obtained.



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## 1. INTRODUCTION

Subsequent to a land based navigation exercise carried out by DRCS in North West Australia in 1980(ref.2), the Royal Australian Navy showed some interest in differential Omega and it was suggested that equipment be installed on HMAS Moresby, a hydrographic survey vessel. This ship carried the ARGO positioning system(ref.4). During operations, a fix would be taken simultaneously by both ARGO and the differential Omega system; the two positions would then be compared.

It was originally planned that a trial, in conjunction with HMAS Moresby, would be conducted during a hydrographic survey of the Joseph Bonaparte Gulf during September/October of 1982. The results obtained in this area could then be compared with those obtained on land in North West Australia(ref.2). Plans were subsequently changed when it was discovered that these were the months set down for maintenance closedown of Omega Reunion and Omega Japan. In the event, HMAS Moresby was unable to undertake the task. As a consequence, the trial was deferred to February/March 1983 when HMAS Moresby was to be working in the Esperance area.

## 2. TRIALS PROCEDURE

This trial differed from those previously conducted by DRCS in two ways:

- (1) Measurements were to be taken on a moving platform. When calculating a position, due allowance had to be made for the movement of the ship during the period over which the data were averaged.

- (2) It was not possible, as in previous land based trials, to compare the base and mobile clocks at frequent intervals in order to make corrections for relative clock drift. As a consequence, the range/range method of navigation previously employed had to be replaced by a hyperbolic method of position fixing, or an equivalent method.

As the ship's speed and heading was known only approximately whilst on board ship, all data were logged and positions recalculated post trial when an accurate speed and heading could be obtained from the ship's track plot.

Moresby's task during February/March 1983 was to undertake a hydrographic survey of the Recherche Archipelago. Accordingly, a base station was set up at OTC Esperance. This allowed operations to a differential distance of up to 150 km. After two weeks of operations, the ship was scheduled to return to HMAS Stirling for refuelling; it was then to continue its task in the Recherche Archipelago. During this period, the base station was moved to Albany airport, thus allowing operations to differential distances of 450 km. Due to unforeseen circumstances, the ship was recalled from its task in early March 1983 and the trial was continued with the base station at Albany and the ship in the Dongara area in May 1983.

At the beginning of the first part of the trial, the mobile unit was zeroed at a surveyed position at the Esperance wharf at 0405 h(UT) on 31 January 1983 and the ship sailed at 0100 h(UT) on 1 February. The unit was rezeroed at HMAS Stirling for the latter part of the trial.

Before sailing, the rate of the mobile clock was set as closely as possible to that of the base station clock using a frequency comparator. The two clocks were rubidium oscillators. It was known that these two clocks would drift relative to each other and a method was devised to calculate this drift post trial. The method used is detailed in Appendix II.

During operations, calculations of position were made using data which were immediately available. An Argo reading was taken simultaneously and the resultant latitude and longitude as calculated from Omega data was compared with that from the Argo equipment. The Argo position was taken as being correct.

Latitudes and longitudes calculated whilst on board ship were treated as being approximate as the ship's speed and heading were not known with sufficient accuracy. All relevant data were logged and the positions recalculated post trial when accurate speed and heading data could be obtained from the ship's track plot.

Position was also calculated from Omega data while the ship was berthed at HMAS Stirling. This was done to verify that errors in position calculated while at sea were produced predominantly by the Omega system and were not introduced during calculation of position by the correction factors applied to allow for the ship's movement. All calculations were based upon data collected while the ship was travelling in a straight line and at constant speed.

Instantaneous phase of Omega transmissions received from Omega Australia, Omega Reunion, and Omega Japan were recorded on floppy disc for the duration of the trial. These data were to be used on return to Salisbury so that positions could be calculated using all three frequencies and a comparison made of the relative merits of each.

### 3. CALCULATION OF POSITION

Basically, the geographical position of the mobile station is calculated using the method detailed in reference 3. A spherical triangle with two Omega stations and the mobile station as vertices is solved to yield the coordinates of the mobile station on the sphere. These coordinates are then iteratively adjusted to give the correct position on the spheroid. The Australian National Spheroid (ANS) is used.

In order to overcome the problems of clock drift, and to enable the drift rate to be estimated, a modified procedure has been employed. The position is calculated three times using three Omega stations taken in pairs. This procedure will, in the presence of errors associated with clock drift and ionospheric de-correlation, yield three different positions. The position given by the coordinates of the in-centre of the triangle, with the three calculated positions as vertices, can be shown to be free from clock error and identical with the result of a hyperbolic system (see Appendix II). The radius of the in-circle is a measure of the clock error at the time of calculation.

4. Readings taken in the Esperance area revealed an RMS error when compared to Argo of 150 m. Figure 1 shows the errors in position fixes taken in the Esperance area. In this figure, the Argo reading is taken as being exact and positions calculated from Omega data are plotted as a distance and azimuth from the Argo position. These results are taken over a differential range of 100 km to 150 km.

The results of the second part of the trial in the Dongara area are taken over a differential range of 500 km to 600 km and a degradation in accuracy is apparent. An RMS error when compared with Argo of 417 m was obtained. The Dongara results are shown in figure 2.

The calculated positional errors are not normally distributed. The

histograms shown in figure 3, figure 4 and figure 5 show the distribution of the magnitude of the positional errors. 90% of all positions calculated during the trial were in error by less than 500 m. There was no appreciable difference in accuracy between readings taken while at sea and readings taken at the wharf at HMAS Stirling.

The positions were calculated on return to Salisbury using speed and heading data taken from the ship's track plot. This resulted in changes in error magnitude of up to 80 m from those calculated using speed and heading data read from the ship's instruments.

Errors in radial distance from the Omega stations were also calculated, due allowance being made for clock drift. Clock drift was calculated by producing a least squares approximation to the clock corrections calculated during the course of the trial (see Appendix II). The radial errors calculated compared favourably with those published in reference 2. Tables of typical results are illustrated in figures 6, 7 and 8.

During the running of the trial, all measurements were observed using the 13.6 kHz frequency. All three frequencies were recorded and positions were calculated using data from all three frequencies for periods when the ship was tied to a wharf. Similar results were obtained for all frequencies.

It should be pointed out that all computations carried out during the trial were based on readings obtained during daylight hours. The recorded data shows that there is a marked decrease in accuracy at night. Figure 9 shows the relative difference in the phase of Omega Reunion as recorded at Albany and HMAS Stirling over a 24 hour period. If perfect correlation existed, this graph would be a straight line showing a constant phase difference. However, it shows marked de-correlation at night. It should be noted that the absolute values of phase angle have no significance in this graph as the plotter was programmed to auto scale the results and to equate the most negative value to zero. A de-correlation of  $1^\circ$  will produce a radial error of approximately 60 m when using the 13.6 kHz frequency.

## 5. CONCLUDING REMARKS

It has been found that accurate navigation is possible during daylight hours using a Differential Omega system. However, there appears to be a marked decrease in accuracy during the night caused by ionospheric de-correlation, even over quite small distances. This night time de-correlation requires further investigation. Since the trial, an American report(ref.6) has been published. This report offers a possible explanation for the poor night time performance. Omega phase and amplitude data were generated using a full-wave mode-theory signal prediction model. Graphs of these data for transmissions from Omega Reunion on a  $120^\circ$  radial and Omega Australia on a  $300^\circ$  radial are reproduced in figures 10 to 13 for day and night conditions. These graphs indicate that the region in which the trial was conducted is subject to modal interference at night.

The errors in calculated radial distance from the three Omega stations are comparable with those obtained in North West Australia.

The Reunion/Australia baseline is a poor choice of baseline for the Esperance area because of the crossing angle of the LOP's (see Appendix II). This baseline was originally chosen for use in the Joseph Bonaparte Gulf.

The practice of passing errors in radial distance from a base station to a mobile station is not a practical method of deploying Differential Omega. To enable all users to make use of such a system it would be better for the base



station to measure its apparent positional change and transmit this change to users as a distance and azimuth. In this way, users with cheap receivers which make use of overlays to determine position could also use differential corrections if they are in range of a differential station.

#### 6. ACKNOWLEDGEMENTS

The trial was conducted under the direction of Mr R.S. Edgar of Radio Group, who manned the shore stations. The author and Mr A.R. Padgham of Radio Group operated the sea-borne equipment during the first and second phases of the trial respectively.

Thanks are due to

- (1) The Hydrographer RAN and staff for permission to conduct the trial on HMAS Moresby and for providing data relating to the trial.
- (2) The Manager, Radio Operations, Overseas Telecommunications Commission for permission to make use of facilities at Esperanceradio.
- (3) OIC Esperanceradio and staff for their assistance during the course of the trial.
- (4) Principal Engineer, Radio Facilities, Airways Engineering, Perth for provision of facilities at Albany Airport.
- (5) Commanding Officer, HMAS Moresby (Cmdr. P. Hardy) for his assistance, advice, and permission to use the facilities on board ship during the trial.

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## APPENDIX I

## EFFECT OF CUTTING ANGLE ON POSITIONAL ERROR

The position calculated by the intersection of two lines of position (LOP) will be in error if the radial distances from the source of transmission are in error. The positional error is dependent upon the errors in radial distance and the angle of intersection of the lines of position.

Considering the earth to be flat over small areas and the LOP to be straight lines over small distances, the effects of small errors in the radius of the LOP on the calculated position is shown below.

With reference to figure 14.

Let  $P_r$  be the actual position of intersection of LOP No.1 and LOP No.2 with no radial error.

Let  $\alpha$  be the intersection angle of LOP No.1 and LOP No.2,  $x_1$  be the error in radius of LOP No.1 and  $x_2$  the error in radius of LOP No.2.

$P_c$  is the calculated position in the presence of errors in the radii of the LOP's.

$e$  is the magnitude of the positional error.

$$d_1 = \frac{x_1}{\sin(\alpha)}$$

$$d_2 = \frac{x_2}{\sin(\alpha)}$$

$$e^2 = \frac{1}{\sin^2(\alpha)} [x_1^2 + x_2^2 + 2x_1x_2 \cos(\alpha)]$$

The above shows that the angle of intersection of the LOP's should be as close as possible to  $90^\circ$ .

## APPENDIX II

### CALCULATION OF CLOCK CORRECTION FACTOR

Unless the clocks in both the base and the mobile equipments maintain precise synchronism (and this is not to be expected when rubidium oscillators are employed in a trial lasting several months) it becomes necessary to introduce a clock correction factor when calculating latitude and longitude from differential data.

An algorithm has been developed which relates the phase error between clocks and the error in computed radial distance from the Omega stations.

If the latitude and longitude of the mobile station is calculated using three baselines, three different apparent positions will result. A triangle formed by joining these three points can be used to find the apparent clock error. It is assumed that the ionosphere is stable over the area of operation and that all errors are due to clock drift. The result is then added to the original information and a true position calculated.

Referring to figure 15.

S1, S2, and S3 are Omega stations. P is the actual position of the mobile station and P1, P2 and P3 are the calculated positions. Point P can be in one of two positions relative to P1, P2 and P3.

#### Case No.1

Point P is inside the triangle P1-P2-P3.

The line P2-P3 lies on the circumference of a circle with centre S3 and radius R3.

The line P1-P2 lies on the circumference of a circle with centre S2 and radius R2.

The line P1-P3 lies on the circumference of a circle with centre S1 and radius R1.

P2-P3, P1-P2 and P1-P3 are small compared with the respective radii and can be considered as straight lines. The earth is considered to be flat over the area concerned. The error introduced by the clock must affect each calculated radial distance equally, therefore the perpendicular distances from P to P2-P3, P1-P2 and P1-P3 must be equal. Clearly, the radius of the inscribed circle of the triangle P1-P2-P3 is the required distance correction factor. The distance can be converted to phase angle and the appropriate phase corrections can be made to the clock.

#### Case No.2

Point P is outside the triangle P1-P2-P3.

In this case, the point P will still be equidistant from P2-P3, P1-P2, and P1-P3 but this time the correction factor will be the radius of one of the E-scribed circles of the triangle P1-P2-P3. This is easily shown by Euclidian geometry.

In Australian operations, when making use of Omega Australia, Omega Reunion and Omega Japan, case No.2 was not expected and, as a consequence, was not considered in the algorithm used.

The lengths of the sides of the triangle and the internal angles were calculated using Robbins(ref.5) formula for the inverse geodetic problem. The magnitude of the correction factor was then calculated using the usual formula for the radius of the inscribed circle:

$$r = \frac{\sqrt{(s-a)(s-b)(s-c)}}{s}$$

where a, b and c are the lengths of the sides of the triangle

s is half of the perimeter

r is the radius of the inscribed circle

The sign of the correction factor is determined from the longitudes of the points P1, P2 and P3.

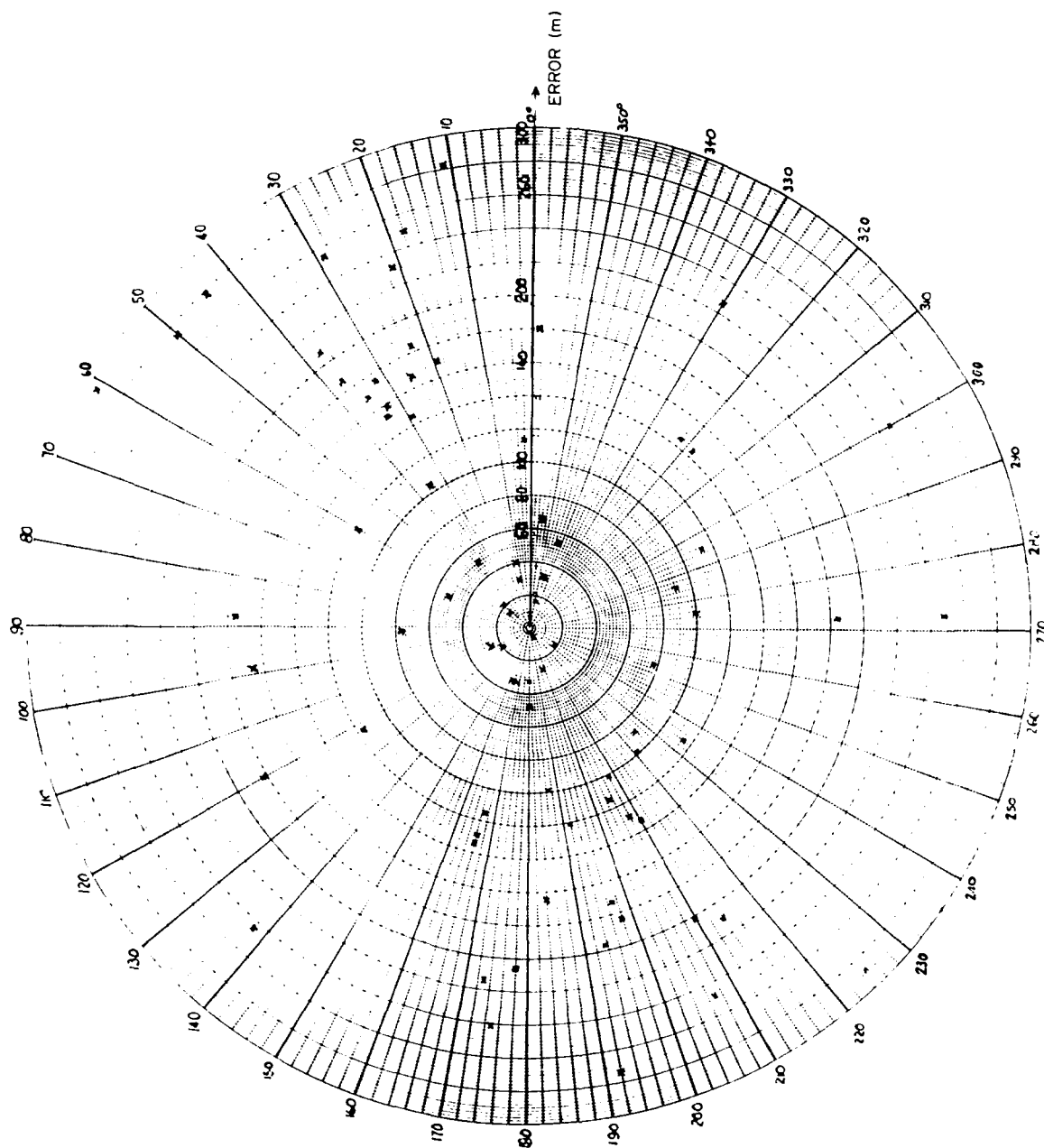


Figure 1. Positional errors - Esperance area

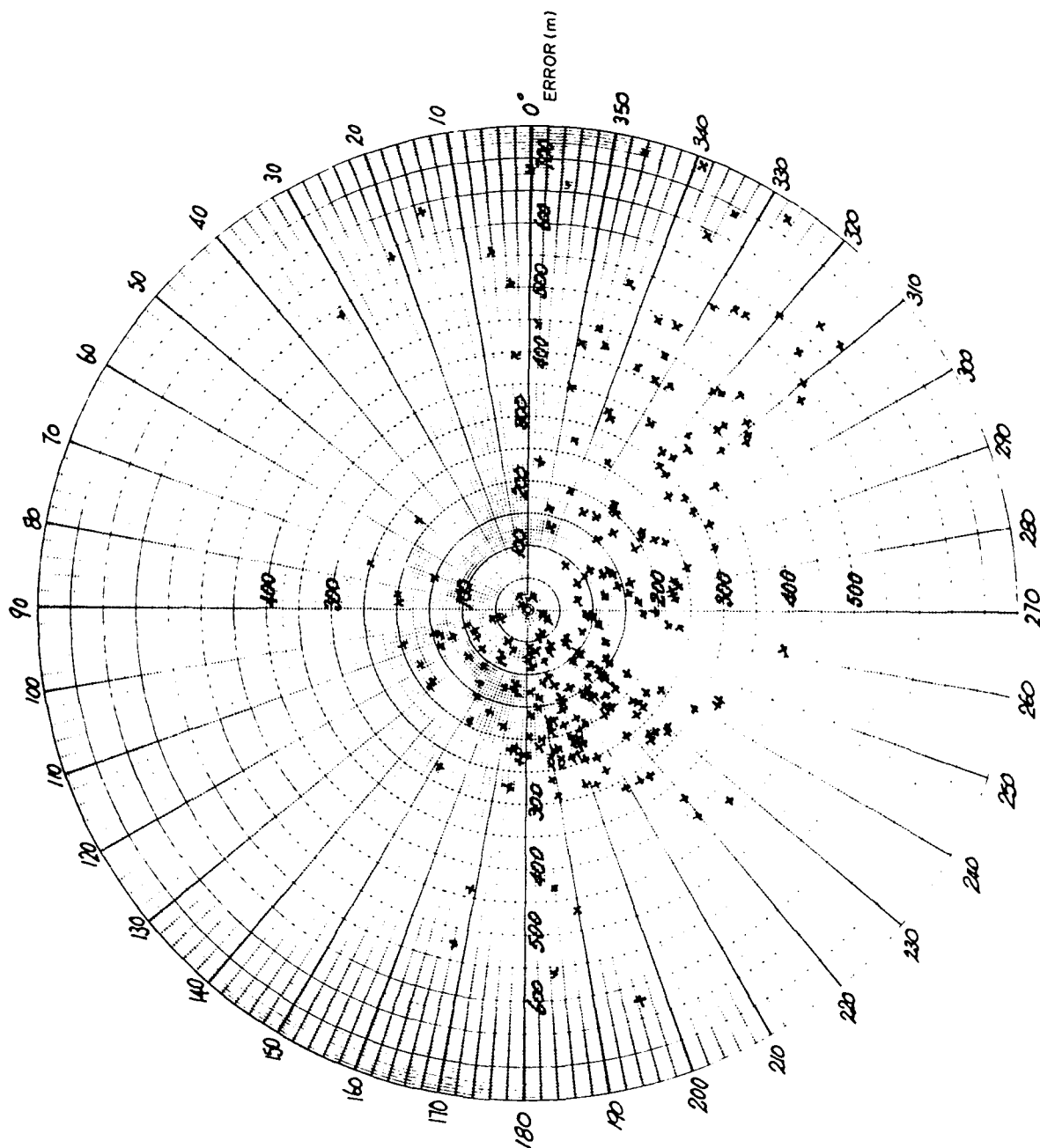


Figure 2. Positional errors - Dongara area

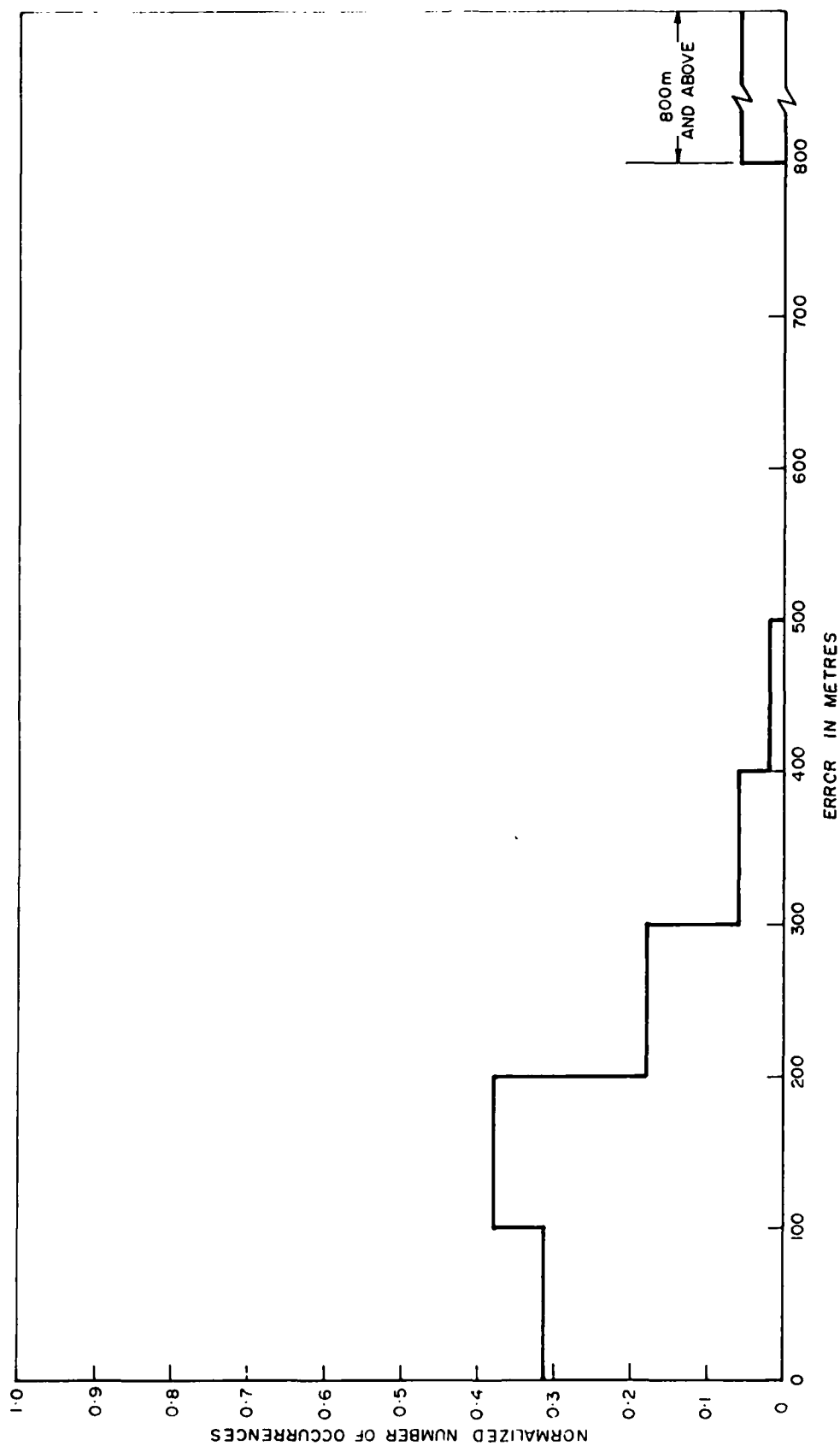


Figure 3. Histogram of positional errors - Esperance area



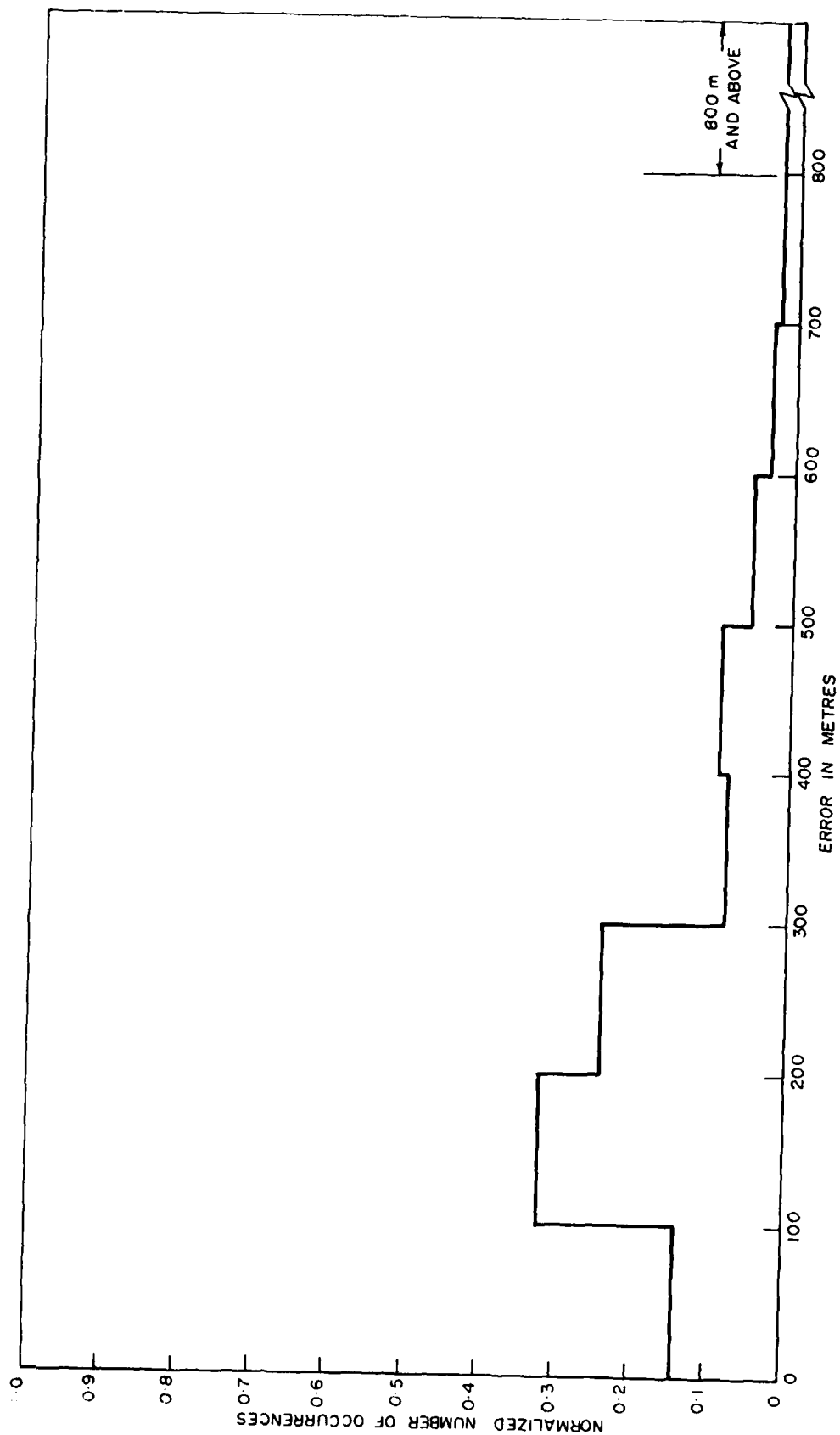


Figure 4. Histogram of positional errors - Dongara area

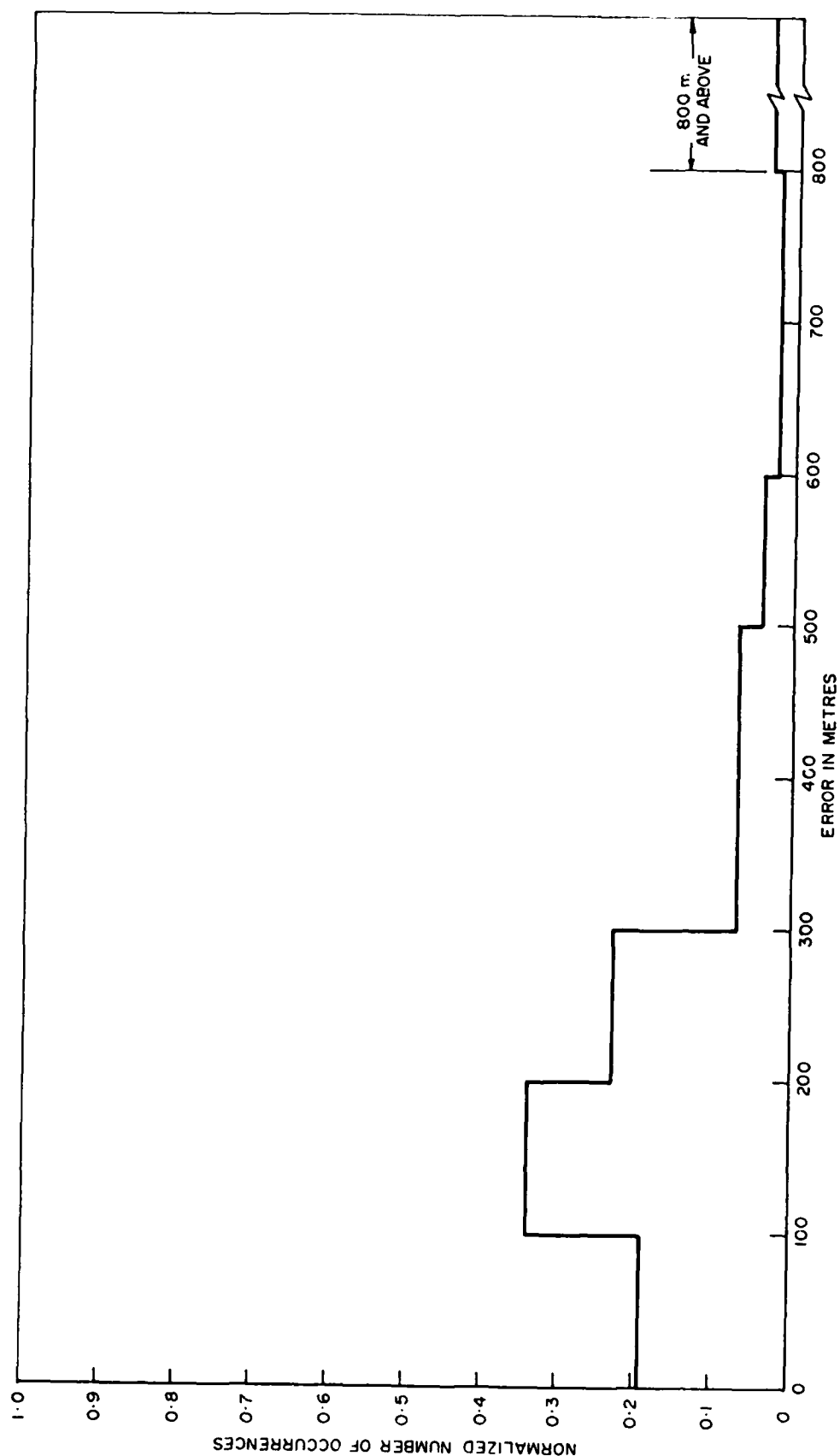


Figure 5. Histogram of positional errors - all observations

POSITION IS HYPERBOLIC ESTIMATE

DAY 38  
DATE 7:2:83

Baselines used are (1) Australia - Reunion  
(2) Reunion - Japan  
(3) Japan - Australia

Ship was at sea, Esperance area.

TIME (UT)	ARGO POSITION	OMEGA POSITION	ERROR	
			MAG	ANG
02:15:49	-34:31:36.3 122:06:26.9	-34:31:36.6 122:06:26.3	18 m	@ 236
02:30:49	-34:31:50.1 122:10:09.3	-34:31:49.8 122:10:05.4	100 m	@ 275
03:00:49	-34:32:11.2 122:14:32.7	-34:32:16.5 122:14:30.7	173 m	@ 197
03:50:49	-34:35:08.9 122:12:20.9	-34:35:03.0 122:12:24.8	116 m	@ 122
04:05:49	-34:35:10.3 122:17:23.3	-34:35:11.9 122:17:23.3	49 m	@ 180
04:20:49	-34:35:15.5 122:22:24.0	-34:35:18.7 122:22:23.5	99 m	@ 187
04:35:49	-34:35:16.6 122:27:26.1	-34:35:20.3 122:27:23.7	129 m	@ 208
07:50:49	-34:36:02.5 122:28:55.1	-34:36:09.4 122:28:56.1	214 m	@ 173
08:13:19	-34:36:06.2 122:22:32.2	-34:36:06.3 122:22:35.3	76 m	@ 92
08:25:49	-34:36:00.5 122:18:56.9	-34:36:08.3 122:18:57.7	241 m	@ 175
08:38:19	-34:35:57.4 122:15:26.2	-34:36:06.2 122:15:23.9	277 m	@ 192
08:50:49	-34:35:59.1 122:11:58.1	-34:35:59.9 122:11:57.8	26 m	@ 197

Figure 6. Typical errors in position : ship moving

## POSITION IS HYPERBOLIC ESTIMATE

DAY 56  
DATE 25:2:83

Baselines used are (1) Australia - Reunion  
(2) Reunion - Japan  
(3) Japan - Australia

Ship was at anchor in Experance area (off of Boxer Island).  
Argo was used to fix ship's position.

TIME (UT)	ARGO POSITION	OMEGA POSITION	ERROR	
			MAG	ANG
02:54:09	-33:59:26.7 122:48:35.0	-33:59:28.6 122:48:37.3	93 m	@ 141
03:14:09	-33:59:26.3 122:48:34.3	-33:59:21.1 122:48:36.4	171 m	@ 19
04:06:39	-33:59:24.1 122:48:33.7	-33:59:17.8 122:48:33.8	195 m	@ 1
04:24:09	-33:59:26.2 122:48:35.0	-33:59:20.9 122:48:34.9	163 m	@ 360
04:44:09	-33:59:25.5 122:48:35.0	-33:59:23.8 122:48:40.9	54 m	@ 342
05:01:49	-33:59:23.9 122:48:33.5	-34:59:21.7 122:48:33.2	68 m	@ 354
05:24:09	-33:59:24.3 122:48:34.4	-33:59:23.0 122:48:34.7	41 m	@ 12
05:41:39	-33:59:24.1 122:48:33.8	-33:59:23.2 122:48:34.1	28 m	@ 12
06:09:09	-33:59:25.7 122:48:34.9	-33:59:23.1 122:48:34.4	79 m	@ 351
06:19:09	-33:59:23.4 122:48:32.8	-33:59:21.2 122:48:35.8	53 m	@ 39
07:06:39	-33:59:23.0 122:48:32.5	-33:59:21.1 122:48:36.5	118 m	@ 60
07:21:39	-33:59:22.7 122:48:32.7	-33:59:17.4 122:48:37.6	205 m	@ 37
07:39:09	-33:59:23.0 122:48:33.7	-33:59:28.8 122:48:40.1	241 m	@ 137
07:56:39	-33:59:21.9 122:48:31.3	-33:59:22.8 122:48:37.7	166 m	@ 99
08:29:09	-33:59:21.7 122:48:29.7	-33:59:21.4 122:48:36.4	174 m	@ 87
08:44:09	-33:59:26.5 122:48:32.1	-33:59:26.5 122:48:37.2	190 m	@ 136

Figure 7. Typical errors in position : ship stationary

RADIAL ERRORS AFTER REMOVAL OF ERROR DUE TO CLOCK DRIFT

DAY 38  
DATE: 7:2:83

Ship was at sea, Esperance area.

TIME (UT)	RADIAL ERROR (m)		
	AUSTRALIA	REUNION	JAPAN
02:14:49	26	54	26
02:30:49	-72	115	-32
03:00:49	3	64	-138
03:50:49	71	-21	-82
04:05:49	-22	-30	-111
04:20:49	49	46	-105
04:35:49	53	147	-46
07:50:49	114	30	-114
08:13:19	126	-32	55
08:25:49	116	34	-159
08:38:19	68	117	-200
08:50:49	37	62	20

Figure 8. Typical radial errors

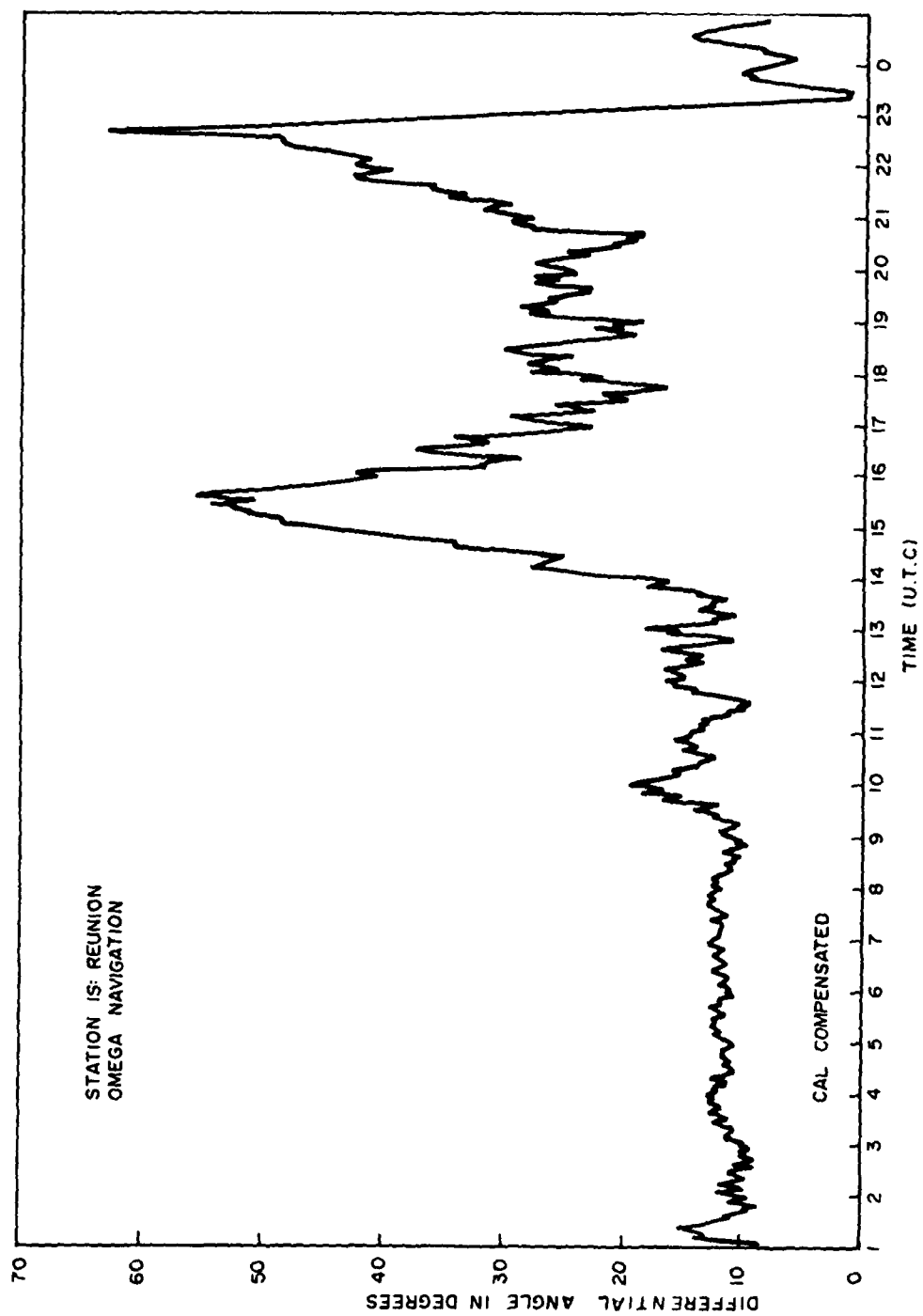


Figure 9. Differential Albany/HMAS Stirling

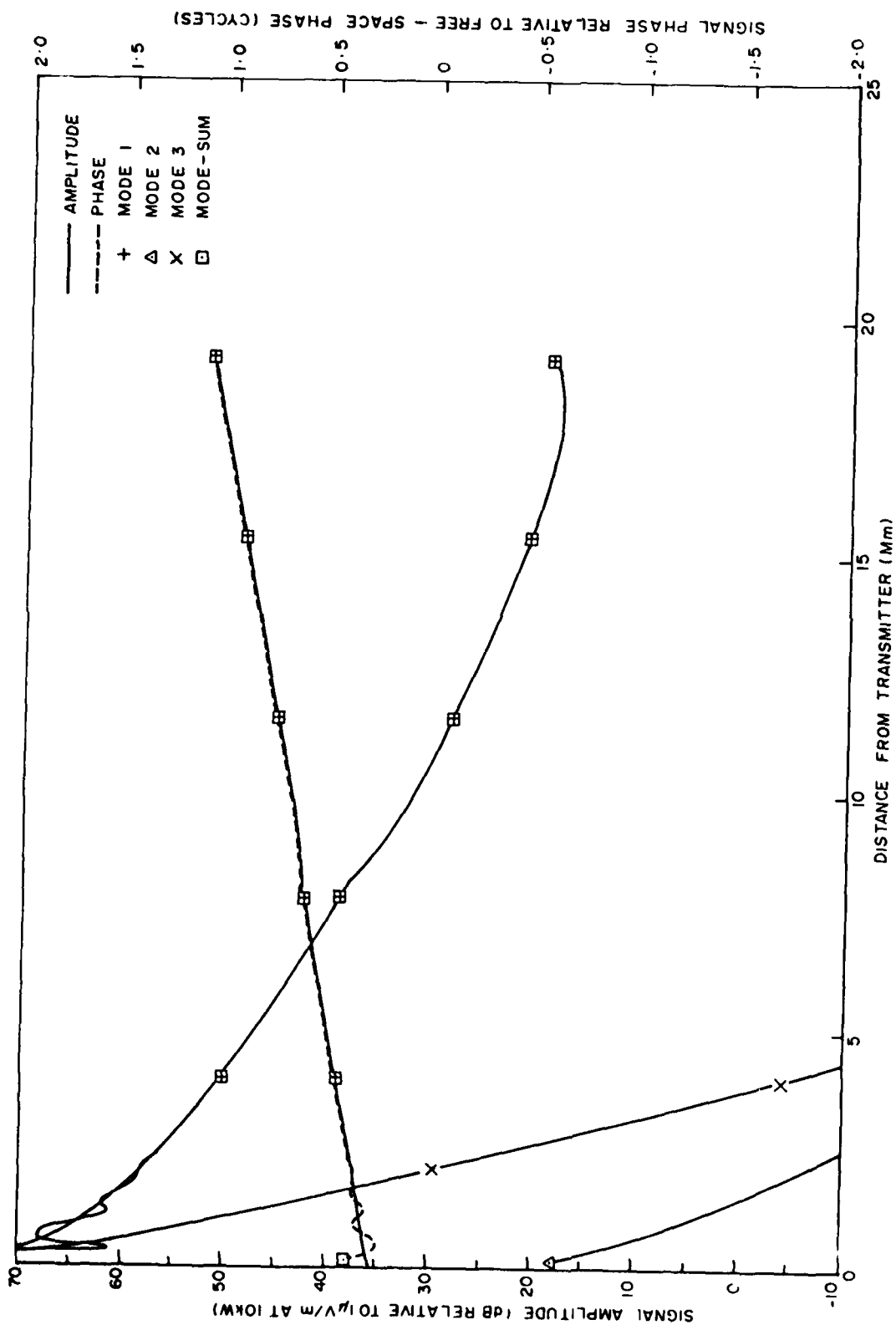


Figure 10. La reunion 13.6 kHz signal : day, 120° radial

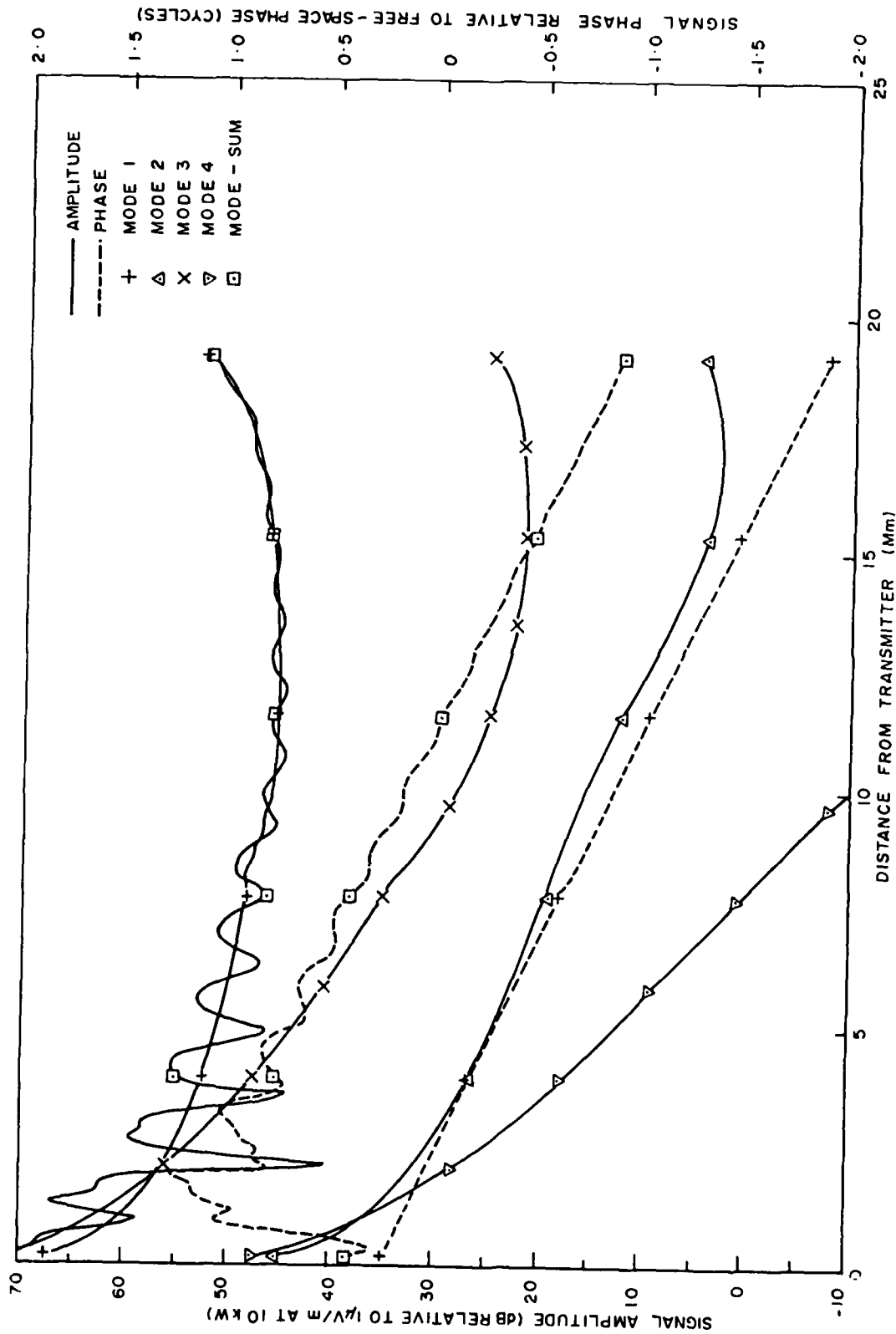


Figure 11. La reunion 13.6 kHz signal : night, 120° radial



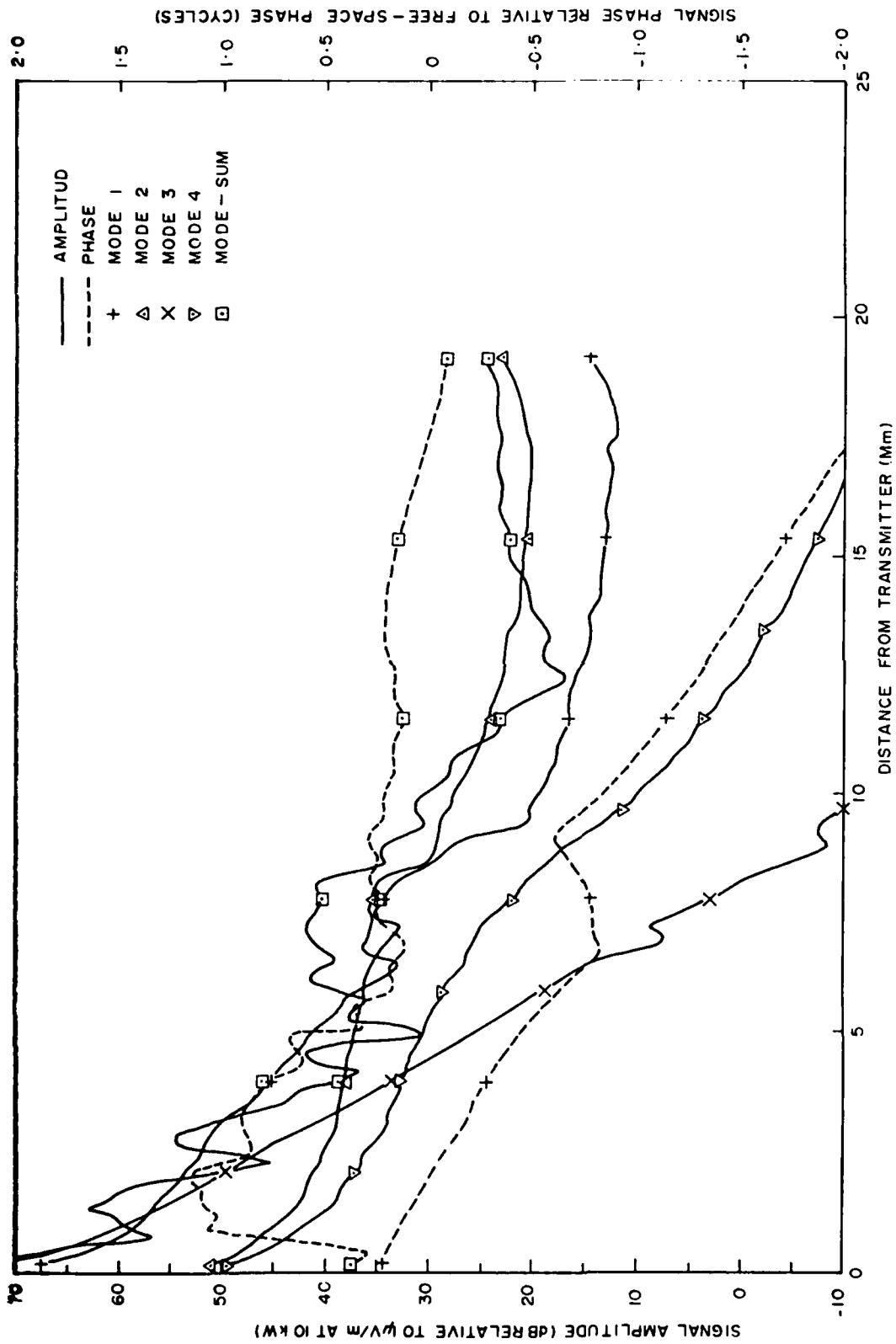


Figure 12. Australia 13.6 kHz signal : night, 300° radial

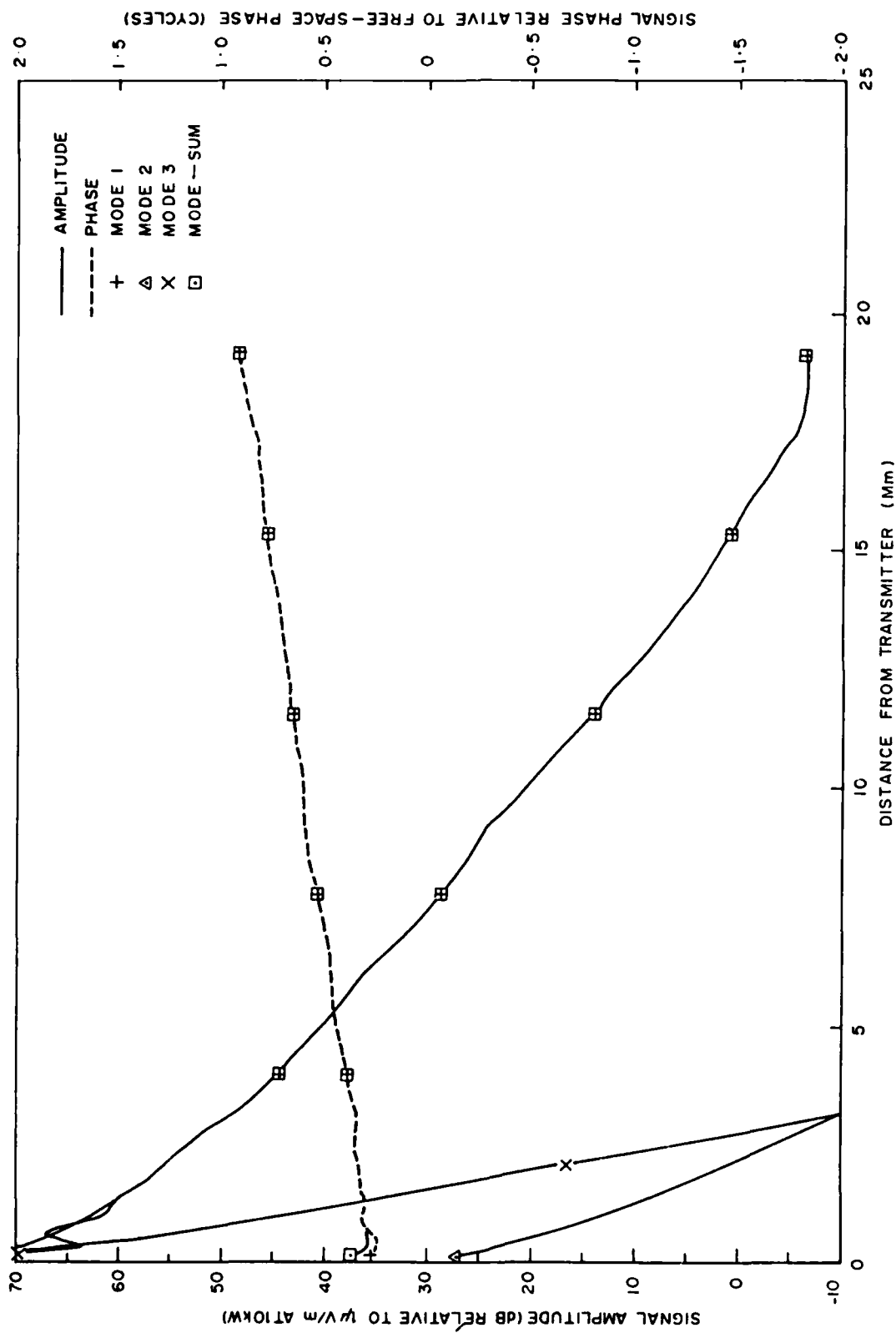


Figure 13. Australia 13.6 kHz signal : day, 300° radial

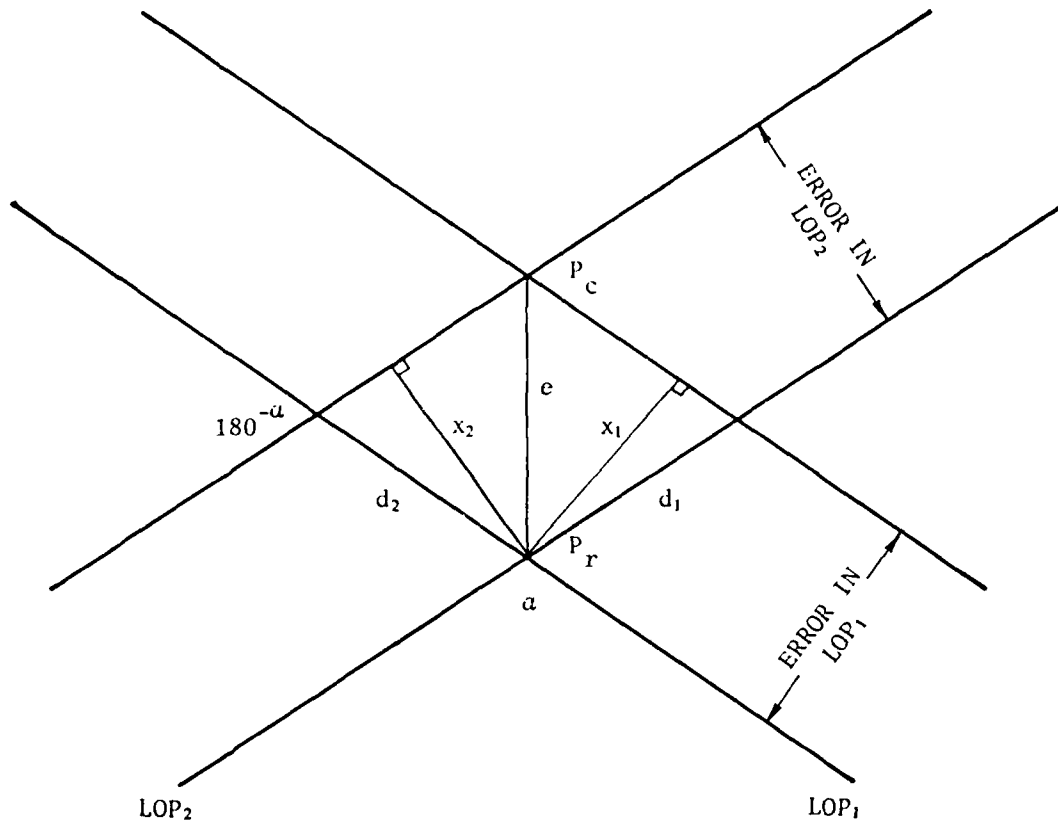
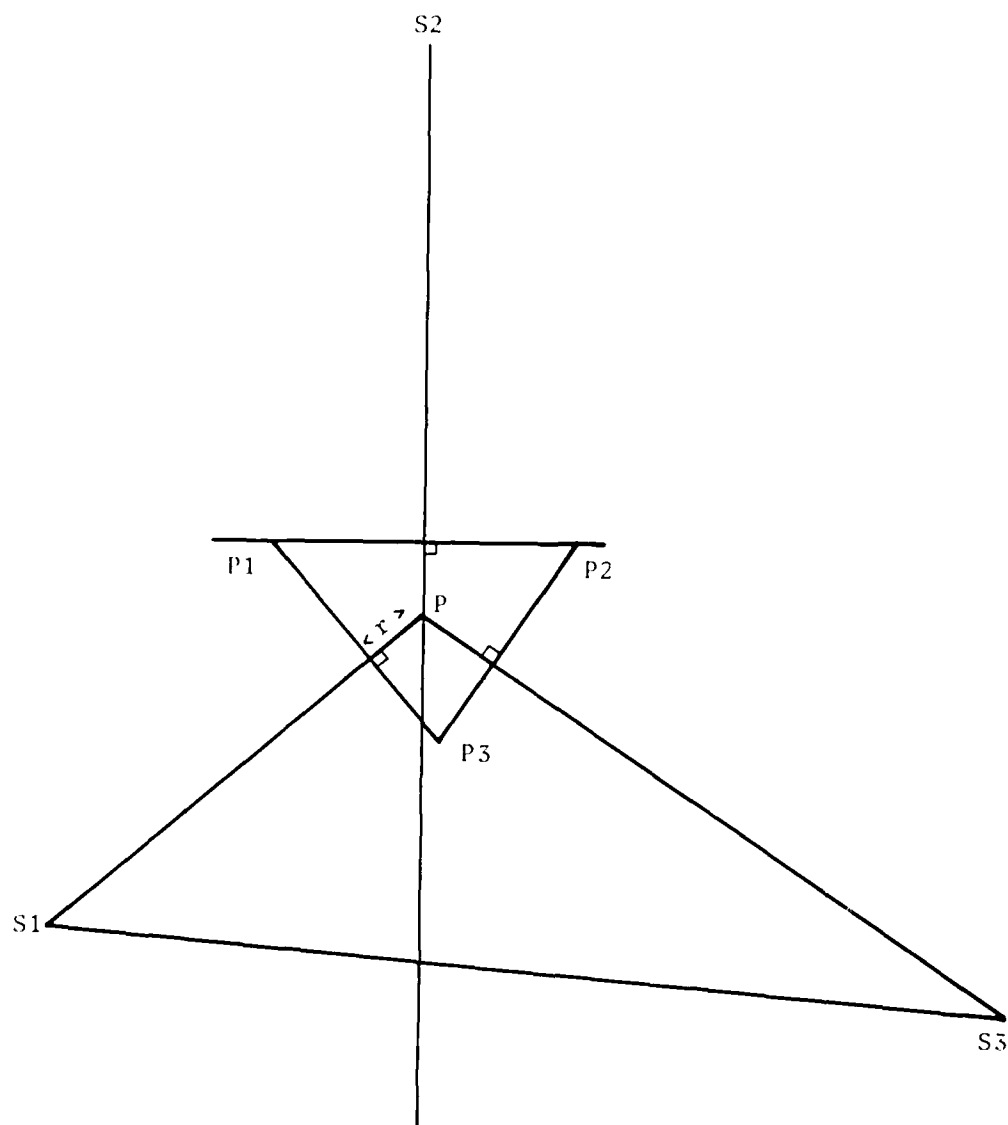


Figure 14. Effect of radial error on position



P3 IS POSITION CALCULATED USING S1 AND S3  
P1 IS POSITION CALCULATED USING S1 AND S2  
P2 IS POSITION CALCULATED USING S2 AND S3  
r IS THE RADIAL ERROR DUE TO CLOCK DRIFT  
P IS ACTUAL POSITION

Figure 15. Error due to clock drift

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A Sea trial was conducted in the first half of 1983 to test the accuracy of Differential Omega at sea and to compare the results with those obtained on land in the Pilbara region in 1980. Base stations were established at Albany and Esperance in Western Australia. Position measuring equipment utilising the Differential Omega system was set up on board HMAS Moresby and positions obtained by the Differential Omega system were compared with those obtained by the Argo system. This report describes the exercise and discusses the results obtained.

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